Original Article

Innovative Comparison on the Performance of TiCN Coated Drill Bit and Uncoated Drill Bit in the Novel CNC Drilling of LDX 2205 Duplex Stainless Steel for Minimizing Roundness Error

Venkatasaikumar Chekuri[1], C. Thiagarajan[2]

[1]Research Scholar, Department of Automobile Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India, 602105.
[2]Project Guide, Corresponding Author, Department of Automobile Engineering, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences, Saveetha University, Chennai, Tamil Nadu, India, 602105.

Abstract

Aim: This research focuses on minimizing the Roundness Error (RE) of LDX 2205 duplex stainless steel by comparing the performance of the TiCN drill bit and uncoated HSS drill bit in the novel CNC drilling process. **Materials and Methods:** The materials used for drill bits are Titanium Carbonitride (TiCN) coated HSS drill and uncoated HSS drill bit. LDX 2205 duplex stainless steel was used as workpiece. A total of 40 specimens were divided into 2 groups with 80% G-Power calculator, to measure the RE of the workpiece machined with the two drill bits in the novel CNC drilling machine. The control factors were spindle speed, cutting force, tool geometry, rate of feed, and drill depth. **Results:** Observed results were recorded and analyzed using SPSS Software. Final experimental values of RE were investigated and obtained, having mean RE value of 0.0400 mm for the HSS drill bit and mean RE value of 0.0287 mm for the TiCN drill bit. Significance value of this study was 0.032 which is less than 0.05 ($p<0.05$). **Conclusion:** Within the limits of this study, TiCN drill bit had lower RE when compared to the HSS drill bit in the novel CNC drilling of LDX 2205 duplex stainless steel.

Keywords: LDX 2205 duplex stainless steel, Roundness Error, CNC drilling, Novel machining, TiCN drill bit, HSS drill bit.

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INTRODUCTION

In this experimental study, the Roundness Error (RE) of the LDX 2205 duplex stainless steel was reduced by applying a coating of Titanium Carbonitride (TiCN) on the conventional HSS drill bit during the novel CNC drilling, and then statistically compared with the HSS drill bit to find out the best tool for this novel machining operation. Computer Numerical Machines (CNC) were started using in the industries in the late 1950's. As the machines were operated by computer the dimensions of the product were accurate and needed less manpower and time to manufacture the products and also to machine any products it became less effort (Ghatge et al. 2018). Drilling, one of the machining processes, the hole made by the drill will always be in imparticular shape due to the uneven surface of drill bit, less strength, less hardness. Roundness error of the conventional HSS drill bit was more, to reduce the error we used TiCN coating. (Vlase et al. 2014). Due to its high tensile strength, machinability, high resistance to chloride stress corrosion cracking, hardness, erosion to fatigue failure, it is used in many heavy-duty machines, Constructions, chemical storage tanks, automobile industry, atomic power plants, marine industry, and military applications (Kumaresan, Machlin Jawahar, and Senthilkumar 2019), here (Kabaso 2014). This study contributes to the reduction of post drilling machining time and to the secondary machining works which delivers a more dimensional accuracy product with better tool life.

In this research field there are about 3025 research papers published in Google Scholar, and about 2485 research papers published in the Science Direct websites in the past 5 years. In the work of (Jirapattarasilp and Kuptanawin 2012) the roundness error was reduced during turning process. In this work the roundness error of stainless steel was minimized using turning parameters in novel machining. In the work of (A. Z. Sultan, Sharif, and Kurniawan 2015) the effect of input parameters on hole quality was found during drilling of AISI 316L stainless steel. In this study the researcher obtained optimized machining parameters for reducing roundness error. Roundness error, shear strain and cutting forces of stainless steel were studied by (Kadam, Khake, and Mudigonda 2017) during

the turning process. In that study, the author proved that coated carbide inserts gives better performance than uncoated inserts in the turning process. Machinability studies of 2205 and 2507 duplex steel were analyzed by (Nomani et al. 2013). In this research the authors found the optimized machining parameters for drilling of various grades of duplex stainless steel. Among all these studies, the best suited experimental study to this research was done by (Kadam, Khake, and Mudigonda 2017). In this work the comparison of performance of TiAlSiN (3.3 µm), AlTiN (3 µm) and AlTiN (7 µm) was done. In this research the researcher proved that coated inserts perform better than uncoated inserts during turning of super duplex stainless steel. Shear strain, cutting forces, roundness error, wear resistance during novel turning of super duplex stainless steel were also analyzed in this study.
Our team has extensive knowledge and research experience that has translate into high quality publications(Bhansali et al. 2021; Jayanth et al. 2021; Sudhakar, Ravel, and Perumal 2021; Sathiyamoorthi et al. 2021; Deepanraj et al. 2021; Raju et al. 2021; Arun Prakash et al. 2020; Kamath et al. 2020; Shanmugam et al. 2021; Rajasekaran et al. 2020; Adhinarayanan et al. 2020; Rajesh et al. 2020; Aurtherson et al. 2021). In this field, there were many researches done before regarding the novel machining of duplex stainless steel, comparing the performance of two tools, decrement of roundness error, etc, but the comparison of RE of TiCN drill bit with HSS drill bit in novel CNC drilling of LDX 2205 duplex stainless steel was not done previously. Coated tools can give more dimensional accuracy product and also more tool life (Rosca et al. 2021). Wear resistance, hardness, surface finish of tools can be improved by applying coatings like: TiAlN, AlTiCrN and TiCN (Ahmad Zubair Sultan, Sharif, and Kurniawan 2020). So it can be predicted that RE can be reduced by coating the tools such as TiCN coating which is used in this study. The purpose of this research is to reduce the RE of HSS drill bit by applying a coating of TiCN and then the statistical comparison between the performance of two drill bits to find out the best tool for this novel machining operation.

Materials and Methods

The Novel CNC drilling of the workpieces was conducted in Saveetha Industries, Saveetha School of Engineering (SSE), Saveetha Institute of Medical and Technical Sciences (SIMATS), Chennai. The sample size of the specimens was predicted using an online clinical sample size calculator and it was found to be 20 specimens per each group with 80% G-Power value for better accuracy during novel machining process. 40 specimens of workpieces were divided into 2 groups and named as control group and experimental group. Drilling with an uncoated HSS drill bit was considered as a control group and drilling with TiCN drill bit was considered as an experimental group. In the work done by (Kumar and Packiaraj 2018) the mean RE value for HSS drill bit was 2.39333 and standard deviation 0.7463 during CNC drilling process.
In this research, the material used for the workpiece is LDX 2205 Duplex Stainless Steel. Workpiece samples were machined into the dimensions of 50 mm height and 20 mm diameter as required for the drilling. Material composition of LDX 2205 duplex stainless steel is shown in Table 1 and physical properties are mentioned in Table 2. In this research work, an uncoated High-Speed Steel (HSS) drill bit with 10 mm diameter was used for novel CNC drilling of LDX 22205 duplex stainless steel samples. It is cost efficient and can maintain hardness in high temperatures that occur during drilling operation. This HSS drill bit used in this experiment is purchased from Addison & Co., Ltd which is shown in Fig. 1. Tool composition is shown in Table 3.
In this research, TiCN coated High-Speed Steel (HSS) drill bit with 10 mm diameter was used for novel CNC drilling of LDX 2205 duplex stainless steel samples. Titanium carbonitride is a very hard ceramic material which is used for coating of the cutting tools to improve the hardness, wear resistance, performance, tool life. TiCN coated tools give better performance in cutting, punching and molding operations. This tool was purchased from Addison & Co., Ltd which is shown in Fig. 2. Tool composition is shown in Table 3.
This experiment was carried out by using the YCM EV1020A Novel CNC machine which is shown in Fig. 3. Maximum spindle speed was set to 4000 rpm and positioning accuracy of 0.01mm with overall maximum power consumption of 50 KVA. The drill bit was fixed to an automatic tool changer's tool holder. The tool holder is adjustable for fixing the tool and the specimen is fixed in the machine. Machining parameters such as spindle speed and rate of feed were programmed in the CNC machine's program memory. Initially the uncoated HSS drill bit was fixed to the tool holder in the CNC spindle for drilling the first 20 specimens from the control group. After the 20 specimens were drilled, then the uncoated HSS drill bit was replaced with TiCN drill bit for drilling the next 20 specimens from the experimental group.
The program cycle was set to drill the samples one by one. The time taken for the novel machining of each specimen was deliberately noted. Each specimen was measured using the vernier caliper for their internal diameter and depth of cut of the specimen that are needed for the calculations. After machining the workpieces were cleaned and the roundness error was measured. Arbitrarily measuring any 3 points on the machined surface of the workpiece gives the average roundness error. Average of 3 readings are considered as the final mean roundness error of the specimen. Roundness error values of the both sample groups were calculated and tabulated as shown in Table 4.

Statistical Analysis

The SPSS v.28 statistical software was used to calculate mean, standard error and standard deviation. The significance level is considered when the probability value $p < 0.05$. In this work a total of 40 samples were taken for analysis so that a 95% confidence level can be achieved (Abas et al. 2020). In this experiment, the independent variables were: Cutting speed, feed rate, and tool type. The dependent variable involved in this experiment was RE. The Independent sample T-test was used to identify the significance among the HSS drill bit and TiCN drill bit.

Results

Material composition of LDX 2205 duplex stainless steel and properties have been shown in Tables 1 and Table 2 respectively. Chemical composition of both drill bits is shown in Table 3. After the novel machining process, the specimens were cleaned and the RE of each specimen in both the groups were calculated and tabulated as shown in Table 4. For both experimental group and control group the machining parameters like feed rate, cutting velocity, spindle speed, depth of cut, type of coolant and machining environment were the same to avoid any external factor affecting the RE of the workpiece. From the group statistical analysis in Table 5, it was observed that the mean RE of TiCN drill bit was 0.0287 mm with standard deviation of 0.00512 and standard error mean obtained was 0.00115.

The mean RE for the uncoated HSS drill bit was 0.0400 mm with standard deviation of 0.01031 and standard error mean was 0.00231. Table 6, shows the Independent sample T-test output values, from the table it is observed that the significance value $p = 0.032$ ($p < 0.050$). Mean difference between the Roundness Error (RE) of the experimental group and control group is 0.01131 mm as shown in Table 7. The nomenclature of the HSS drill bit and TiCN drill bit are shown in Fig. 1 and Fig. 2 respectively. Fig. 3 illustrates the image of the CNC machining center. The comparison between the RE values of TiCN drill bit and HSS drill bit is shown in graphical form (Fig. 4). This graph clearly shows that TiCN drill bit gives better mean accuray with lower error deviation in this novel machining operation.

Discussion

From the results of this experimental study, it can be clearly observed that the mean RE for TiCN drill bit was 0.0287 mm with a standard deviation of 0.00512 which is lower than the mean RE of HSS drill bit with the value of 0.0400 mm and standard deviation of 0.01031 as shown in Table 5. Significance of this comparative study is found to be 0.032 which was less than 0.05, and the analysis was performed with a confidence level of 95%, as shown in Table 7. Comparison of mean RE of uncoated HSS drill bit and TiCN drill bit was represented using a clustered bar graph as shown in Fig. 4. From the graph it is proven that the coated tools can bring minimum RE than the uncoated tools (Talib et al. 2015). This is due to higher hardness, better tool geometry even at high forces, and better abrasion resistance of TiCN coated cutting tools (Bhanu Prakash and Thiagarajan 2021), (Irfan et al. 2019). The results of the above researchers are in line with this study. Findings of this study are in compliance with the findings of (Kumar and Packiaraj 2018). In their work, the mean hole quality of uncoated HSS during drilling of OHNS steel was similar to the result obtained in this research and got even less RE due to coated tools used in this research. Cutting force, shear strain angle, chamfer angle, and feed rate, were the significant factors for reducing roundness error (Jayaganth et al. 2018). The conclusion achieved by that author was not inline with the results of this work. This conflict arises due to the reason that machining parameters were varying by the researchers in each drilling process in order to reduce the roundness error but in this research the input parameters were kept constant and used coated tools (TiCN drill bit) to bring minimum RE.

In the novel drilling process the machining parameters play an important role (Maruda and Szczotkarz 2016). In this research the machining parameters like cutting speed, feed rate, type of tool are the factors which affect the result (RE) of this study. Limitations of this experimental study were extremely slight deformities in tool coating, inconsistent tool wear after novel machining, under close inspection criteria the tool was completely eroded on the edges and surface of the tool, and cost of TiCN coating. Future scope of this research study can be carried out using different materials used in coating, effect of coolant, and various layers of coating, different workpiece material which can further reduce the Roundness Error.

Conclusion

From this experimental study, it is proven that the minimizing of RE of the LDX 2205 duplex stainless steel can be achieved by applying a coating of TiCN over the conventional HSS drill during the novel CNC drilling process, by concluding from the mean RE result obtained for TiCN drill bit was 0.0287 mm which is lower than the mean RE of HSS drill bit with the value of 0.0400 mm. RE values on machined surfaces were recorded, analyzed and

statistically compared using the independent sample T-Test in the SPSS Statistical software. In this performance comparison it is concluded that the TiCN drill bit gives better performance in this novel machining process.

DECLARATION

Conflict of interest
The authors of this paper declare no conflict of interest.

Authors Contribution
Author VSK was involved in data collection, data analysis, manuscript writing, Author CT was involved in conceptualization, data validation, and critical review of manuscript.

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Tables and Figures

Table 1. LDX 2205 duplex stainless steel - Material composition.

Material	Weight Percentage (%)
Chromium (Cr)	21.8 - 23.5
Nickel (Ni)	4.55 - 6.50
Molybdenum (Mo)	3.00 - 3.50
Manganese (Mn)	2.00 max
Silicon (Si)	1.00 max
Carbon (C)	0.30 max
Nitrogen (N)	0.14 - 0.20

Phosphorus (P)	0.30 max
Sulfur (S)	0.20 max
Iron (Fe)	Balance

Table 2. LDX 2205 duplex stainless steel - Properties (Mechanical & Physical).

Properties	**Values**
Melting Point	1450 °C
Density	7820 Kg/m3
Tensile Strength	620 - 750 MPa
Fatigue strength	767 MPa
Yield Strength	450 MPa
Young's Modulus	200 MPa
Poisson's Ratio	0.32
Specific Heat	418 J/kg-K
Thermal Expansion	13.7 µm/m-°C at 100^0 C
Thermal Conductivity	19 W/m-K at 100^0 C
Electrical Resistivity	850 nΩ.m
Elongation	25%
Rockwell Hardness (HR C)	31 max
Brinell Hardness (HB)	293 max

Table 3. Chemical composition of drill bits (wt %).

Tool	**Cr**	**W**	**C**	**Mo**	**Co**	**V**	**Ti**	**N**	**O**
TiCN	1.3-2.0	-	25-38	-	-	-	23-35	20-30	8-12
HSS	4.0-4.5	18	1.3-1.5	9.60	5	1.20	-	-	-

Table 4. Obtained Roundness Error (RE) values of LDX 2205 Duplex Stainless Steel for both groups: Uncoated HSS drill bits & TiCN drill bits.

Sample No:	HSS drill bit (mm)	Sample No:	HSS drill bit (mm)	Sample No:	TiCN drill bit (mm)	Sample No:	TiCN drill bit (mm)
1.	0.0378	11.	0.0369	1.	0.0316	11.	0.0265
2.	0.0385	12.	0.0402	2.	0.0244	12.	0.0479
3.	0.0341	13.	0.0353	3.	0.0288	13.	0.0302
4.	0.0328	14.	0.0311	4.	0.027	14.	0.0223
5.	0.0336	15.	0.0335	5.	0.0259	15.	0.0271
6.	0.0349	16.	0.0287	6.	0.028	16.	0.0267
7.	0.0405	17.	0.0475	7.	0.0251	17.	0.0259
8.	0.0342	18.	0.0457	8.	0.0286	18.	0.0271
9.	0.0742	19.	0.0496	9.	0.0282	19.	0.0312
10.	0.037	20.	0.0536	10.	0.0312	20.	0.0298

Table 5. Group statistics: Mean RE, Std. Deviation, and Std. Error mean obtained for uncoated HSS drill bit & TiCN drill bit for a total sample size of 20 specimens per group.

Group	N	Mean	Std. Deviation	Std. Error Mean
TiCN drill bit	20	0.0287	0.00512	0.00115
HSS drill bit	20	0.0400	0.01031	0.00231

Table 6. Levene's test for equality of variances & the T-test for the equality of means for both uncoated HSS drill bit and TiCN drill bit with a obtained significance value of 0.032 ($P < 0.05$).

Hypothesis	F	Sig.	t	df
RE - Equal variances assumed	4.944	0.032	4.393	38
RE - Equal variances not assumed			4.393	27.843

Table 7. T-Test for the equality of means of the roundness error. Assumed hypothesis of existence of the equal variance among the control group is true with the obtained significance value of 0.032.

Hypothesis	**Significance (2-Tailed)**		**Mean Difference**	**Std. Error difference**	**95% Confidence interval of the Difference**	
	1- sided p	**2- sided p**			**Lower**	**Upper**
RE - Equal variances assumed	< 0.001	< 0.001	0.01131	0.00257	0.01652	0.00610
RE - Equal variances not assumed	< 0.001	< 0.001	0.01131	0.00257	0.01658	0.00604

Fig. 1. High-speed steel (HSS) twist drill bit (10 mm) with high heat resistance and easily machinable, widely used for application for drilling. HSS is the most commonly used cutting tool in industries.

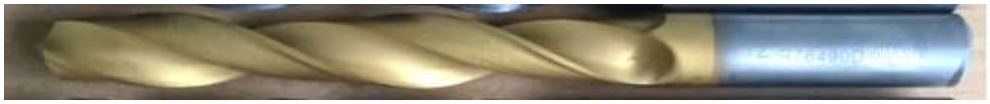

Fig. 2. Novel Titanium Carbonitride coated on HSS twist drill bit (10 mm) having yellow refractory coating on High-speed steel that improves hardness, wear resistance and gives more tool life**.**

Fig. 3. YCM EV1020A CNC machining center. Specifications: Maximum spindle speed- 4000 rpm, Cutting speed- 150 m/min, Feed rate- 0.50 mm/min, drill depth- 30 mm, Swing over bed- 500 mm, Swing over carriage- 260 mm, No. of Stations- 8, Distance between centers- 425 mm.

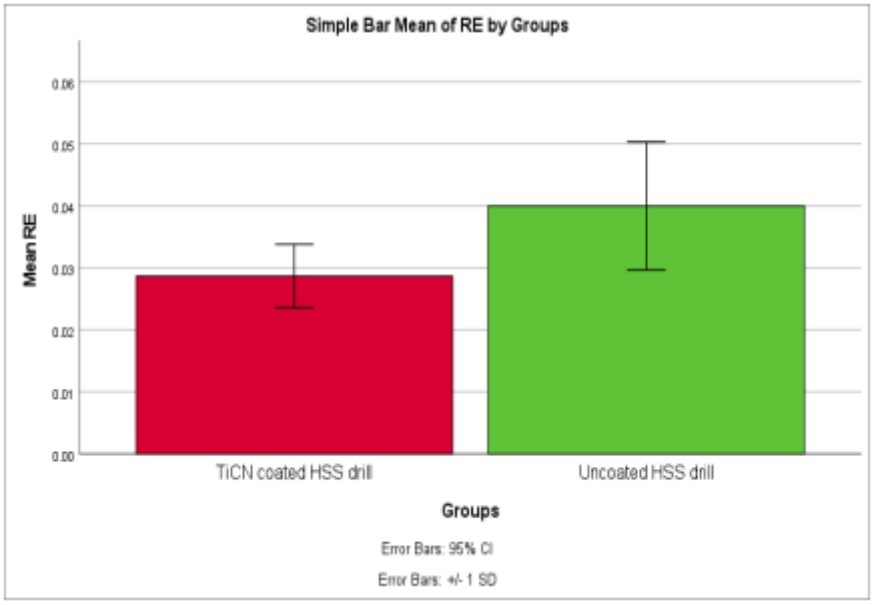

Fig. 4. In this bar graph the mean RE difference between the groups is shown. Comparison of TiCN drill bit and HSS drill bit in terms of mean accuracy. Mean RE for TiCN drill bit is 0.0287 mm and mean RE for HSS drill bit is 0.0400 mm. The mean accuracy of the TiCN drill bit is better than HSS drill bit and had lower error deviation. X-axis denotes type of tool and Y-axis denotes the mean roundness error. Mean accuracy of detection $\pm$ 1 SD.